BIOMECHANICAL INDICATORS OF HALF-MARATHON RUNNING

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ABSTRACT
The half-marathon originated from the marathon as its length is half a marathon or 21.0975 km. This discipline is one of the newest in the World Athletics program, as the first major championship of this distance was in 1992 in England. Even earlier, the running community created distance as an alternative to marathon running in the 50s of the 20th century. Despite its relatively long history, there is little data on the biomechanical indicators of the competitors participating in the discipline. Hence, the present study aims to determine the leading indicators characterizing running speed in the half-marathon discipline and the influence of fatigue on these indicators. To achieve the study's goal, we implemented the following tasks: 1) Measurement of the main characteristics of the running speed in 3 sections of the racing distance, 2) Determination of the variability of these indicators. To solve the study tasks, we used video analysis and statistical methods. After the analyses, we find differences in the length and frequency of the strides of competitors with different qualifications. Highly trained athletes (HT) had a more even pace (1:00-3:04 min per section) than moderately trained athletes (MT) (3:25-5:19 min per section). HT athletes had greater stride length (1.61-1.70 m) than MT athletes (1.50-1.54 m) in all sections. MT athletes rely more on stride frequency than on stride length to increase their movement speed. HT athletes are opposite MT athletes. Conclusions: 1) The results obtained show the possibilities for using drones for the needs of kinematic analysis in running 2) From the differences in running speed, we can determine that VT athletes manage to distribute their efforts more evenly over the competition distance than the MT athlete; 3) The decrease in speed at the end of the competition distance in VT athletes is mainly due to the shorter stride length.

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INTRODUCTION

Running is a form of physical activity that is one of the most widely practiced, as evidenced by the thousands of competitions around the world, in which millions of amateurs and professionals with different motivations for sports participate (Running USA, 2016; Hulteen et al., 2017; De Leeuw et al., 2018; Kozlovskaia et al., 2019; Slavchev et al., 2023; RunSignup, 2025). In recent years, a trend has emerged in world athletics to include several disciplines in separate championships. That is also the case with road running championships. These include the half-marathon, 5 km, and 1 mile (Slavchev et al., 2023). Long-distance running includes all disciplines whose length is longer than 3000m. Another classification can be made based on the running surface. For this reason and the growing popularity of road running, World Athletics created a world road running championship, which includes the disciplines of the half-marathon, 1 mile, and 5 km. The half-marathon originated from the marathon as its length is half a marathon or 21.0975 km. This discipline is one of the newest in the World Athletics program, as the first major championship of this distance was in 1992 in England. Even earlier, the running community created distance as an alternative to marathon running in the 50s of the 20th century. The oldest half-marathon held annually is the Route du Vin Half Marathon in Luxembourg, whose first event was in 1962 and is still held today. Despite its relatively long history, there is little data on the biomechanical indicators of the competitors participating in the discipline. Despite this interest in the discipline and its role as a physical activity, we found a relatively small number of literary sources on the topic. At the same time, we are in a high-tech era, in which the acquisition of information and the speed with which it is analyzed are staggering. All this is made possible by unmanned aerial vehicles (UAVs) and high-speed computers.

The present study *aims* to determine the leading indicators characterizing speed in the half-marathon discipline and the influence of fatigue on these

indicators. To achieve the study's goal, we implemented the following tasks: 1) Measurement of the main characteristics of the running speed/study of the frequency and length of running steps in 3 sections of the racing distance, 2) Determination of the variability of these indicators.

METHODS

Participants

The study population consisted of 33 participants in the half-marathon of the Stara Zagora Marathon, which also served as the National Half-Marathon Championship. Finishing times ranged from 1:07:24 to 1:28:11. Based on their results, participants were divided into two groups: highly trained (HT) runners (≤ 1:15:00; n = 10) and moderately trained (MT) runners (> 1:15:00; n = 23).

Procedure

Measurements were conducted on pre-defined and marked sections of the race course, each 1 m in length, positioned at 600–650 m, 11.200–11.250 m, and 20.450–20.500 m of the half-marathon distance. Video capture was performed using a DJI Mini 4 Pro UAV (DJI Technology Co. Ltd.) equipped with a 1/1.3-inch sensor, f/1.7 aperture, and 2.4 μm pixels. The drone supports dual native ISO, 4K HDR video, and slow-motion recording at 4K resolution. It was positioned laterally to the runners, at a height of 18 m and 20 m from the near edge of the track.

Measures

The video data were analyzed using Kinovea software. The main recorded parameters were the average stride frequency and the stride length. Based on these data, the speed of movement was calculated using the formula $V = L \times T$, where V = speed, L = stride length, and T = stride cadence. To determine the distribution of effort during running, the average speed for each quarter of the distance was calculated using the formula $v = S/t$.

The official race results are publicly available on the Stara Zagora Marathon website: https://results.sporthive.com/events/7311080089314131968.

Data Analysis

Statistical analyses were performed using Microsoft Excel 2016 (Version 16.0; Microsoft Corporation, Redmond, WA, USA) and Jamovi (Version 2.6; The Jamovi Project, 2024). The applied statistical methods included descriptive statistics**,** frequency analysis**,** the Shapiro–Wilk test**,** and ANOVA**.**

RESULTS

The results obtained after the conducted studies on the dynamics of running speed for the two studied groups are presented in Tables 1 and 2. On average, trained athletes cover the four intervals of the race distance in the following times: 17:06 minutes, 17:36 minutes, 17:42 minutes, and 18:02 minutes. This group shows the most significant variability about the last part of the race distance.

Table 1. *Descriptive statistics of the measured split times of HT athletes*

Statistical indicator	*First quarter*	*Second quarter*	*Third quarter*	*Fourth quarter*
Mean	0:17:06	0:17:36	0:17:42	0:18:02
Me	0:16:58	0:17:33	0:17:44	0:18:10
Mo	0:16:58	0:17:12	N/A	N/A
SD	0:00:31	0:00:24	0:00:38	0:00:57
R	0:01:32	0:01:00	0:02:03	0:03:04
Min	0:16:06	0:17:12	0:16:44	0:16:38
Max	0:17:38	0:18:12	0:18:47	0:19:42
V%	3.0	2.3	3.6	5.3

The amateurs, on the other hand, completed the four intervals of the race distance in times of 19:37 min, 20:27 min, 20:00 min, and 20:34 min. The most significant variability in this group was again registered in the last part of the race distance.

Table 2. *Descriptive statistics of the measured split times of MT athletes*

Statistical indicator	*First quarter*	*Second quarter*	*Third quarter*	*Fourth quarter*
Mean	0:19:37	0:20:27	0:20:00	0:20:34
Me	0:20:02	0:20:11	0:20:11	0:20:20
Mo	0:20:03	0:19:09	N/A	N/A
SD	0:01:08	0:01:08	0:00:53	0:01:14
R	0:04:13	0:04:08	0:03:25	0:05:19
Min	0:17:30	0:19:09	0:18:30	0:18:21
Max	0:21:43	0:23:17	0:21:55	0:23:40
V%	5.74	5.55	4.38	6.00

The speed reduction in the HT group ranges from-0.38 % to -3.02%. At the same time, this variation is greater for the MT group in the range of (-4.26 to +2.39).

Table 3. *Speed dynamics of the splits of half-marathon runners*

Speed Group	First quarter speed (m/s)	Second quarter speed (m/s)	Speed change 1 (%)	Third quarter speed (m/s)	Speed change 2 (%)	Fourth quarter speed (m/s)	Speed change 3 (%)
HT	5.15	5.00	-3.02	4.99	-0.38	4.87	-2.08
MT	4.49	4.30	-4.26	4.4	2.39	4.27	-3.03

The biomechanical parameters studied, stride length and frequency, are shown in Figure 1. In the first section of the race distance, the stride length of average trained athletes is 1.73 m, and for amateurs, it is 1.54 m. For the same section, the stride frequency of the average trained athletes is 3.13 Hz, while for amateurs, it is 2.99 Hz. In the second section of the distance, the stride length of the average trained athlete is 1.73 m, while for amateurs, it is 1.50 m. At the same time, the stride frequency is 3.05 Hz for the average trained athletes and 2.93 Hz for the amateurs. In the last part of the race, the stride length and frequency are as follows: 1.61 m and 2.95 Hz for the average trained athletes, and 1.50 m and 3.09 Hz for the amateurs.

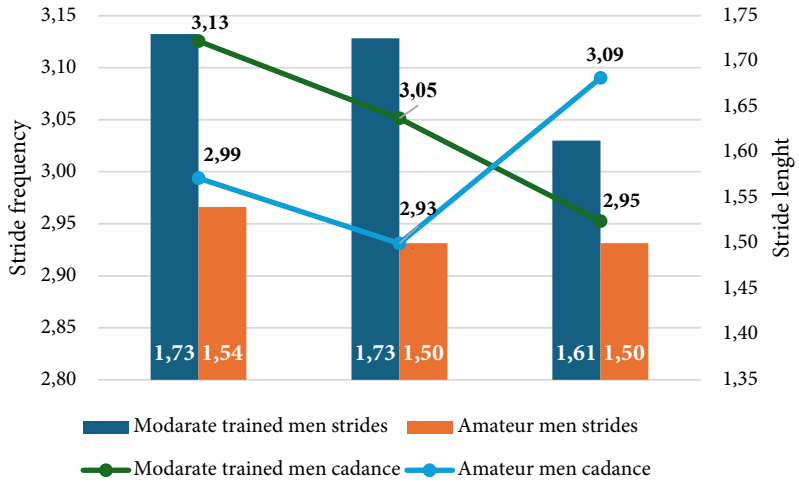

Figure 1. *Kinematic characteristics of half-marathon running for HT and MT athletes*

Each of the measured indicators has a normally distributed variable, as indicated by the Shapiro-Wilk coefficient ($p > .05$). One-way analysis of variance (ANOVA) with Tukey's post hoc tests shows that there is a statistically significant difference between the two groups of competitors in the stride length in the first two sections ($F = 22.12$ and $F = 24.37$, $p < .05$) and no such difference in the final part of the competition ($p > .05$). Regarding the stride frequency, we found no difference between the level of competitors and the stride frequency in the individual sections of the competition distance ($p > .05$). No difference is observed between the three studied moments in the competition regarding the stride frequency for the HT group. At the same time, MT competitors show a statistically significant difference only between the stride frequency at the middle and end of the competition distance ($F = 9.47$, $p < .05$). Unlike the frequency in terms of stride length between the beginning and the end, and the middle and the end of the race distance, statistically significant differences were observed in highly skilled athletes ($F = 5.70$ and $F = 9.74$, $p < .05$).

DISCUSSION

The use of modern techniques and methodologies in sports practice is the basis for optimizing sports training (Bhasi, 2019; Rangasamy et al., 2020; Russomanno et al., 2022). From this perspective, the use of quadcopters for capturing video footage for biomechanical analysis is innovative and the first of its kind in athletics. The use of drone technology is also recognized in various other areas of life (Kardasz et al., 2016; Rakha et al., 2018; Islam, 2020; Mali & Dey, 2020; Ayamga et al., 2021). As for sports science, there are only a few studies that focus on rowing and running (Romanowski et al., 2017; Balasubramaniam et al., 2023a; Balasubramaniam et al., 2023b; Jacob, 2024).

The problem of human potential and its maximum realization has always aroused the interest of sports specialists (Weiss et al., 2016). For the full realization of the athlete's current capabilities, the appropriate distribution of efforts is of particular importance. That is evidenced by the large number of publications on the topic and its definition as Pacing in sport refers to the conscious or subconscious regulation of performance in order to achieve a goal (Thiel et al., 2018). A topic that has been thoroughly researched in sports, through which it is concluded that a uniform pace is the basis of a higher ranking and a better final time (Thiel et al., 2012; Hanley, 2015; Casado et al., 2021).

In the methodological literature, there is a prevailing belief that as movement speed decreases, the time spent in contact with the support increases. Although this fact is a law to us, some authors question it. Regarding the half-marathon, studies confirm this opinion, as well as those that do not support it (Santos-Concejero et al., 2013; Gómez-Molina et al., 2017; Ogueta-Alday et al., 2018). Several authors have also investigated the role of foot placement as a factor in sports performance in other studies (Ogueta-Alday et al., 2013; Ogueta-Alday et al., 2014; Ogueta-Alday et al., 2018). Other research on kinematic indicators is related to marathon running, specifically distinguishing between fast and slow competitors based on biomechanical indicators (Chan-Roper et al., 2012; Schubert et al., 2014).

Only a few authors have studied the change in speed (effort distribution) during the half-marathon, and to a greater extent than in the marathon (Hanley, 2015; De Leeuw et al., 2018; Cuk et al., 2019; Nikolaidis et al., 2019; Cuk et al., 2020; Casado et al., 2021; Nikolaidis & Knechtle, 2023; Ristanović et al., 2023). According to the authors, the difference in speed decline increases with the decrease in the qualification of the competitors. This finding is partially supported by our study (Ristanović et al., 2023). An interesting fact is that, regardless of their level, the competitors fail to increase their speed at the end of the race (Table 3), contrary to the opinion of other authors (Casado et al., 2021).

According to our results, the two studied groups show a different profile of overcoming the race distance, as in the highly trained, each intermediate section is slower than the previous one (with a lower speed), the reasons for which are not fully understood (Del Coso et al., 2013). Also, BC competitors show better times than MT. At the same time, there is less variability between the individual intervals (De Leeuw et al., 2018; Ristanović et al., 2023). Amateurs, on the other hand, exhibit an uneven profile in overcoming the distance, a finding also confirmed by other studies (Cuk et al., 2020; Ristanović et al., 2023). They also have greater deviations in overcoming the individual intervals. The first interval is the fastest, followed by a decrease in speed, then an increase in the third interval, and a decrease again in the last part of the race. In our opinion, this highlights the impossibility of evenly distributing effort over the competition distance, which may be due to lower qualifications or overestimation of momentary capabilities (Nikolaidis et al., 2019; Ristanović et al., 2023).

The data from the kinematic indicator analysis are shown in Figure 1. From the exact figure, it is clear that the frequency of men's movement decreases across the three studied sections, from 3.13 Hz to 2.95 Hz. At the same time, the step length is maintained in the first two and drastically decreases in the last one (1.73m to 1.50m). The data we obtained for the selected biomechanical parameters are similar to those measured in laboratory conditions by competitors and are highly dependent on movement speed (Schubert et al., 2014; Gómez-Molina et al., 2017b; Ogueta-Alday et al., 2018).

In MT athletes, a minimal decrease in stride length (from 1.54 m to 1.50 m) is observed in the final stages of the race, while their frequency is constantly decreasing (Chan-Roper et al., 2012). At the same time, they manage to maintain a constant stride length, although lower than that of VT. As observed in this study and other similar ones, a decrease in stride length and frequency is noted, which, according to the authors, occurs at the expense of an increase in support time (Chan-Roper et al., 2012). In this line of thought, we must share the understanding of some authors that more experienced athletes run with a higher stride frequency and shorter stride length. However, we have not studied the athletes' sports experience or age in order to comment on this phenomenon (Conoboy & Dyson, 2006; Gómez-Molina et al., 2017; Gómez-Molina et al., 2017b). We refer to a phenomenon observed in our data, which reveals differences in the stride length of VT athletes and the stride frequency of MT athletes. It would also be interesting to determine the stride length ratio to the height of athletes and to derive the corresponding indices and conclusions, as it is a well-established fact that this relationship depends on the height of athletes. On the other hand, long-distance runners, even if they share similar

anthropometric characteristics, generally exhibit considerable variation (Zillmann et al., 2013; Nikolaidis & Knechtle, 2023). MT athletes rely more on stride frequency than on stride length to increase their movement speed. HT athletes are the opposite of MT athletes.

Limitations of the research

This article is limited to a single competition with a small number of researched athletes. Other limitations included the number of parameters, which was two. For future research, we can investigate more angles of the joints. Another limitation is the height-to-stride length ratio, which was not observed, as we could have gained some valuable information about the optimal stride length for runners.

CONCLUSIONS

Based on the conducted studies and the results obtained from them, we can draw the following conclusions for sports practice:

1. The results obtained show the possibilities for using drones for the needs of kinematic analysis in running.
2. From the differences in running speed, we can determine that VT athletes manage to distribute their efforts more evenly over the competition distance than the MT athlete.
3. The decrease in speed at the end of the competition distance in VT athletes is mainly due to the shorter stride length.

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